Supplemental Material: To weight or not to weight: assessing sensitivities of climate model weighting to multiple methods, variables, and domains

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S.1 Maps from the CMIP5 ensembles - precipitation

Among the 288 ensemble means created from this experimental setup, there are numerous times when results are duplicated. For example, applying a given weighting combination created using the full domain to Louisiana would have the same value as the same weighting combination created using the full domain applied to the full domain and examining only the Louisiana area. As such, the results in this and the following sections will focus only on those ensemble means created from the various combinations of weighting schemes applied to the full domain for each ensemble. In this way, one can then examine the effects for the Louisiana and New Mexico domains and other regions of the full domain.

The bias for the CMIP5 ensemble means of precipitation are shown in Figure 7, and they depict the influence of the different weighting schemes. For reference, the precipitation bias of the unweighted ensemble mean shows a tendency to overestimate precipitation in the western portion of the domain and underestimate in the eastern portion of the full domain (Figure 7, larger map on the left). For those ensemble means created with temperature-derived weights (Figure 7, group of maps in the top right), the pattern of bias in precipitation remains consistent but changes in magnitude compared to the unweighted scheme. When weighted for the full domain (Figure 7, group of maps in the top right, top row of figures), the bias pattern of precipitation is similar. When weighted for high temperatures in Louisiana (Figure 6, group of maps in the top right, middle row of figures), the magnitude of underestimation of precipitation in the eastern portion of the domain is smaller. In contrast, when weighted for high temperatures in New Mexico (Figure 7, group of maps in the top right, bottom row of figures), precipitation is underestimated by a larger amount in the eastern portion of the domain compared to the full domain temperature weighting. When precipitation is used to derive the weights (Figure 7, group of maps in the bottom right), the resulting ensemble mean of precipitation is sensitive to the domain used for the weighting. When the full domain precipitation is used for weighting (Figure 7, group of maps in the bottom right, top row of figures), the ensemble mean shows a consistent pattern to the bias of the unweighted ensemble mean. Additionally, the magnitudes of the bias in the full domain are decreased using the BMA weighting scheme, which agrees with the results from Wootten et al. (2020a). When weighted for precipitation in Louisiana (Figure 7, group of maps in the bottom right, middle row of figures), the precipitation bias of the ensemble mean is overestimated across much of the larger domain with a lower bias in Louisiana. In contrast, when weighted for precipitation in New Mexico (Figure 7, group of maps in the bottom right, bottom row of figures), the precipitation bias of the ensemble mean is underestimated across much of the larger domain, particularly in the eastern portion of the domain and when using the BMA weighting.

The future projected change maps of precipitation for the CMIP5 ensemble, shown in Figure 8, are also sensitive to the weighting combination used. The unweighted CMIP5 ensemble mean (Figure 8, larger map on the left) projects a decrease in precipitation across much of Texas and New Mexico, with increases in precipitation projected in the northeast portion of the domain. When weighted for high temperature in the full domain (Figure 8, group of maps in the top right, top row of figures), the pattern remains consistent for each ensemble mean, with an expansion of projected decreases into the northern portion of the domain with the BMA weighting. The area of projected decreases shrinks for three out of four weighting schemes (all schemes except the BMA method) when high temperatures in Louisiana are used to derive the weights (Figure 8, group of maps in the top right, middle row of figures). Using BMA and Louisiana high temperatures to derive the ensemble weighting, the ensemble mean has a similar pattern and magnitude to the ensemble mean created with BMA weights derived using high temperatures in the full domain. In contrast, using New Mexico's high temperatures to derive ensemble weights (Figure 8, group of maps in the top right, bottom row of figures) causes the area of projected decreases in the ensemble mean to shrink to a region along the Gulf Coast, with projected increases in the northeast and northwest corners. Using precipitation in the full domain to derive ensemble weights (Figure 8, group of maps in the bottom right, top row of figures), three of the four weighting schemes have a similar pattern to the unweighted mean, while the BMA weighted ensemble mean has a much weaker drying signal and a large increase in precipitation in the northeast corner of the domain. The greatest contrast between the CMIP5 ensemble means exists between the means created with weights based on Louisiana and New Mexico precipitation (Figure 8, group of maps in the bottom right, middle, and bottom row of figures). When Louisiana precipitation is used to derive ensemble weights (Figure 8, group of maps in the bottom right, middle row of figures), the ensemble mean shows an increase in precipitation across the eastern portion of the domain. The greatest increase in precipitation is in the northeast corner of the domain for three of four weighting schemes, while the greatest increase in the ensemble mean using the BMA weighting derived with Louisiana precipitation is actually in Louisiana. The ensemble mean created with weights derived from New Mexico precipitation (Figure 8, group of maps in the bottom right, bottom row of figures) projects a decrease in precipitation across New Mexico, much of Texas, and all of Louisiana with three out of four weighting schemes. When BMA weights are derived using New Mexico precipitation, the resulting ensemble mean projects a decrease in precipitation across the entire domain, with the greatest magnitude along the Gulf Coast.

S.2 Maps from CMIP5 ensembles – high temperature

There is more consistency in the historical bias and future projected changes of the weighted CMIP5 ensembles of high temperatures, shown in Figure 9, compared to that of precipitation, and these weighted ensembles are less sensitive to the various weighting combinations. The bias of the unweighted CMIP5 ensemble mean high temperature (Figure 9, larger map on the left) shows a tendency to underestimate high temperatures in the western portion of the domain except for some mountainous regions where the bias is variable. When weights are derived using high temperatures in either the full domain or Louisiana (Figure 9, group of maps in the top right, top, and middle row of figures), the pattern remains similar to the unweighted mean regardless of the weighting scheme used. The ensemble means tend to overestimate temperatures east of the Rocky Mountains when the ensemble weights are derived using New Mexico high temperatures (Figure 9, group of maps in the top right, bottom row of figures). When using precipitation in the full domain to derive the ensemble weights (Figure 9, group of maps in the bottom right, top row of figures), the bias for the resulting ensemble means is similar to the unweighted mean, but the high temperature is broadly underestimated when Louisiana precipitation is used to derive ensemble weights (Figure 9, group of maps in the bottom right, middle row of figures). In contrast, when New Mexico precipitation is used to derive ensemble weights (Figure 9, group of maps in the bottom right, bottom row of figures), high temperatures east of the Rocky Mountains are overestimated, particularly in the northeastern portion of the region. However, the magnitude of the overestimate is not as large as the overestimate of high temperatures when the New Mexico high temperatures are used to derive ensemble weights.

As with the high temperature bias, Figure 10 shows that the future projected changes in high temperature in the resulting ensemble means are less sensitive than projected changes in precipitation with the CMIP5 ensemble (i.e. plots in Figure 8). If the full domain precipitation (Figure 10, group of maps in the bottom right, top row of figures) or high temperature (Figure 10, group of maps in the top right, top row of figures) are used to derive the ensemble weights, the ensemble mean change from three out of four weighting schemes tends to have a similar pattern to the unweighted ensemble mean. The weighting with BMA using the full domain high temperatures results in a similar pattern of projected changes in high temperature but concentrates the greatest changes in the northern portion of the domain. Similarly, the weighting with BMA using the full domain precipitation results in a similar pattern of projected changes in high temperature but concentrates the greatest changes on the western edge of the domain. The projected changes in high temperature are larger, particularly in the northwest corner of the domain with BMA, when New Mexico high temperatures (Figure 10, group of maps in the top right, bottom row of figures) or precipitation (Figure 10, group of maps in the bottom right, bottom row of figures) are used to derive ensemble weights. The greatest projected changes in high temperature are in the ensemble mean when created using weights derived with New Mexico precipitation and the BMA weighting scheme. With regards to the Louisiana domain (Figure 10, group of maps in the bottom right, middle row of figures), there is a notable difference in the projected change in high temperature. When the high temperatures in Louisiana are used to derive ensemble weights, the projected high temperature changes follow a similar pattern to the unweighted ensemble mean, however, the projected high temperature changes are less than the unweighted mean and the other ensemble means.

S.3 Maps from the LOCA ensembles – precipitation and high temperature

Previous work by Wootten et al. (2020a) has shown that the future projected changes from a resulting ensemble mean can be sensitive to whether or not downscaling was used in the ensemble. In addition, downscaling also reduces the bias of the individual members of a GCM ensemble. As such, the results in this section will focus on the projected changes of high temperature and precipitation using the downscaled LOCA ensemble.

The precipitation future projected change from the unweighted mean for the LOCA ensemble is shown in Figure 11 (larger map on the left), and displays a similar pattern to the unweighted CMIP5 ensemble (from Figure 8), with a decrease in precipitation projected along the Gulf Coast and a projected increase in the northeast corner of the domain. When weighting is based on high temperature in all three domains (Figure 11, group of maps in the top right), the projected change in precipitation is similar to the unweighted ensemble mean (with some changes in magnitude) for all of the weighting schemes except for BMA. When weighting is based on the full domain and Louisiana high temperatures with the BMA weighting scheme, the LOCA ensemble mean projects an increase in precipitation across much of the eastern and northern portions of the domain, and any area showing a projected decrease is confined to southern Texas. When weighting is derived using New Mexico high temperatures and the BMA weighting scheme, the same region of southern Texas is projected to see decreases in precipitation as the unweighted version and with a larger magnitude. However, when looking at this scheme, the projected increases in rainfall are primarily in the northern area of the domain with lesser magnitude than other BMA weighted means weighted based on high temperature. When using the full domain precipitation to derive ensemble weights (Figure 11, group of maps in the bottom right), the resulting ensemble mean precipitation changes are similar to the unweighted precipitation change, though the BMA weighted version also includes a greater increase in precipitation in the northwest corner of the domain. When weighted on precipitation in New Mexico or Louisiana with the LOCA ensemble (Figure 11, group of maps in the bottom right, middle, and bottom row of figures), the ensemble means for three of the four weighting schemes have a similar projected change to the unweighted ensemble mean. When the ensemble weights are derived using Louisiana precipitation with the BMA weighting scheme, the resulting LOCA ensemble mean projects an increase in precipitation in the eastern portion of the domain, with little to no change in other parts of the domain. The BMA weighted mean of the LOCA ensemble projects a decrease in precipitation along the Gulf Coast and Louisiana and an increase across much of the rest of the domain when New Mexico precipitation is used to derive weights.

The unweighted mean high temperature change for the LOCA ensemble, shown in Figure 12 (larger map on the left) is similar to the CMIP5 ensemble (from Figure 109). For three out of four weighting schemes (all schemes except BMA), the resulting ensemble mean projected change for high temperature tends to be similar to that of the unweighted ensemble mean.

However, the resulting LOCA ensemble mean created with the BMA weighting is sensitive to the domain and variable used to derive weights. When the full domain or Louisiana high temperatures are used with BMA to derive model weights (Figure 12, group of maps in the top right), the mean projected high temperature changes are demonstrably cooler across the entire domain, particularly in the northwest corner of the domain. When New Mexico high temperatures are used to derive the BMA weights, the gradient of the projected change remains consistent except for a cool pocket in southern Colorado and northern New Mexico. In contrast, when the full domain or New Mexico precipitation are used with BMA to derive ensemble weights for the LOCA ensemble (Figure 12, group of maps in the bottom right), the projected changes in high temperature are warmer than the unweighted mean, particularly in the northwest corner of the domain. However, when Louisiana precipitation is used to derive ensemble weights with BMA, the mean change from the LOCA ensemble is cooler than the unweighted mean for much of the domain.

Supplemental Tables and Figures

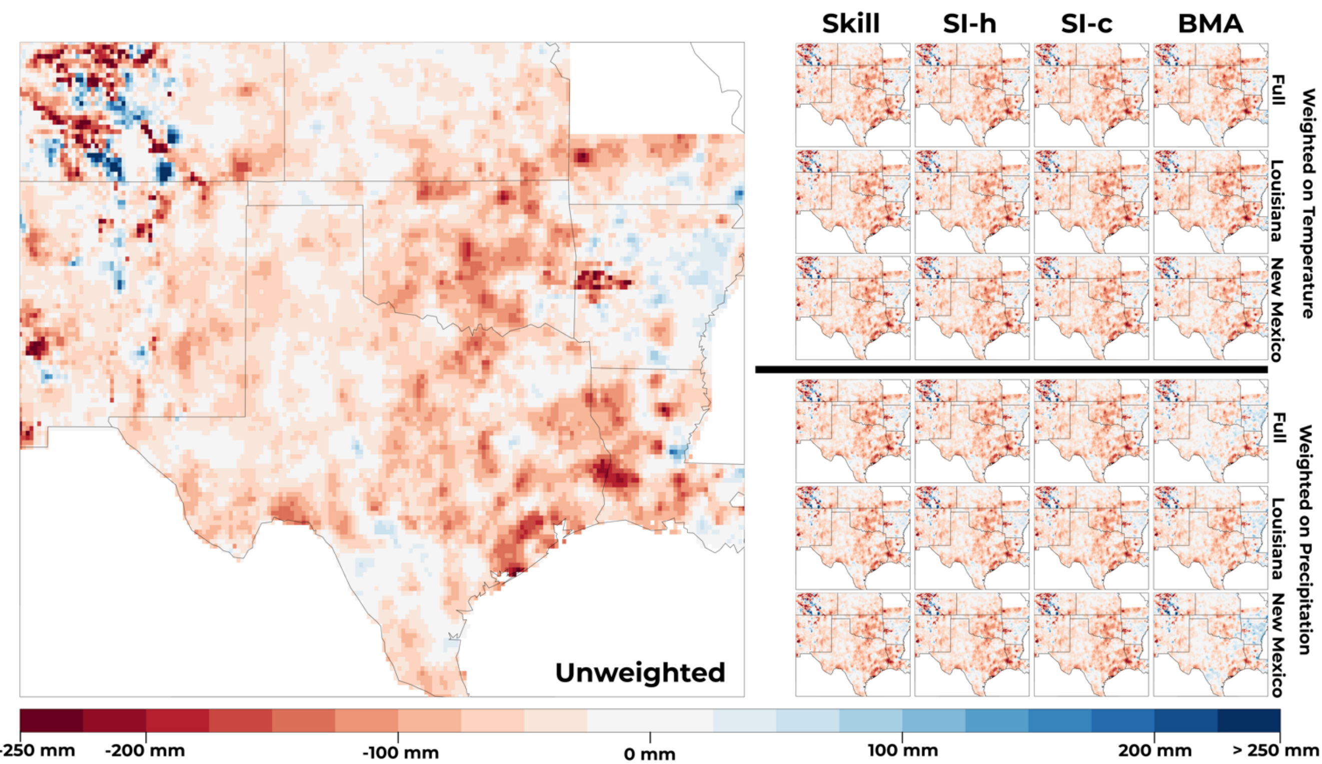

Figure S.1: Bias of LOCA ensemble mean precipitation (1981-2005) from the unweighted ensemble (left) and each weighted ensemble mean (right). On the right side, the columns from left to right are for the Skill, SI-h, SI-c, and BMA weighting schemes respectively. On the right side, the top group of twelve plots are the results for weights derived using temperature (tmax) and the bottom group of twelve plots are the results for weights derived using precipitation (pr). Within a group of twelve on the right hand side, the top row is for weights deriving using the full domain, the middle row is for weights derived using the Louisiana domain, and the bottom row is for weights derived using the New Mexico domain.

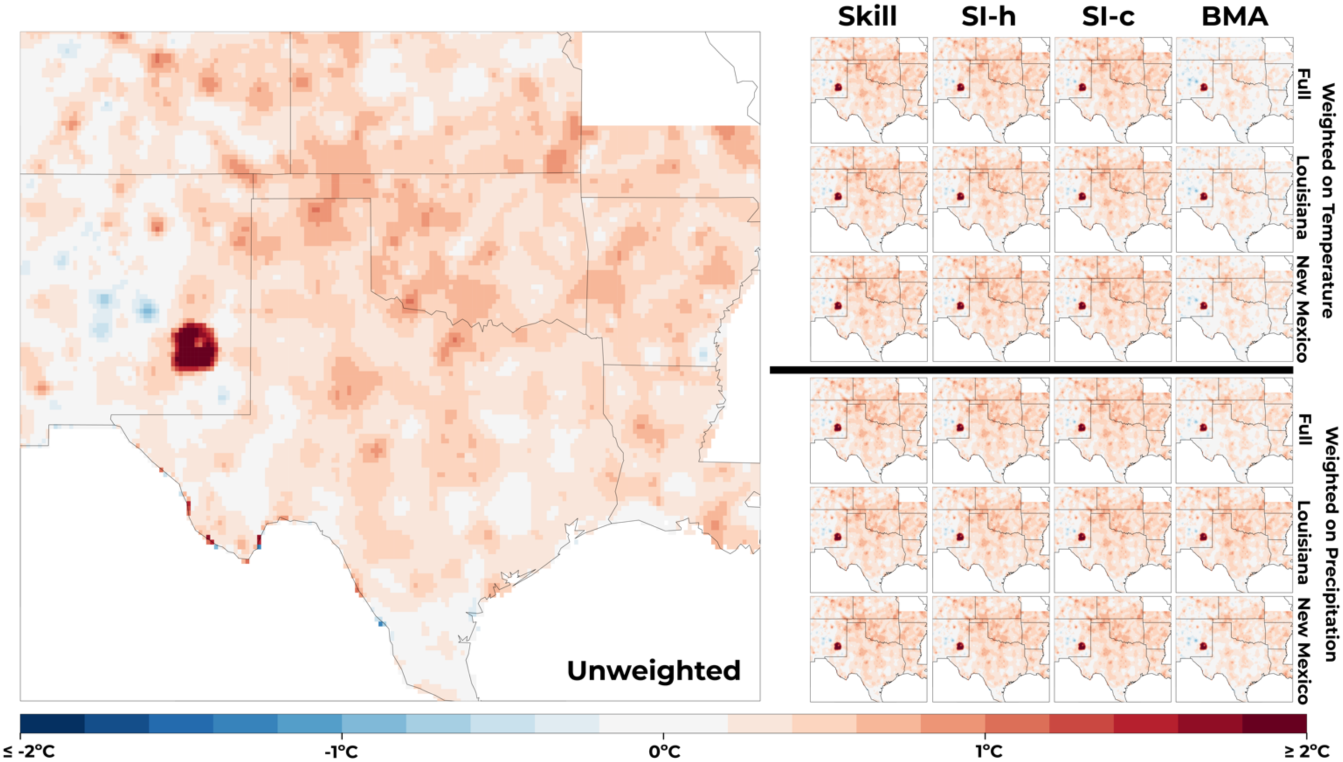

Figure S.2: Same as Figure S1, but for the bias of ensemble mean high temperature of the LOCA ensemble.

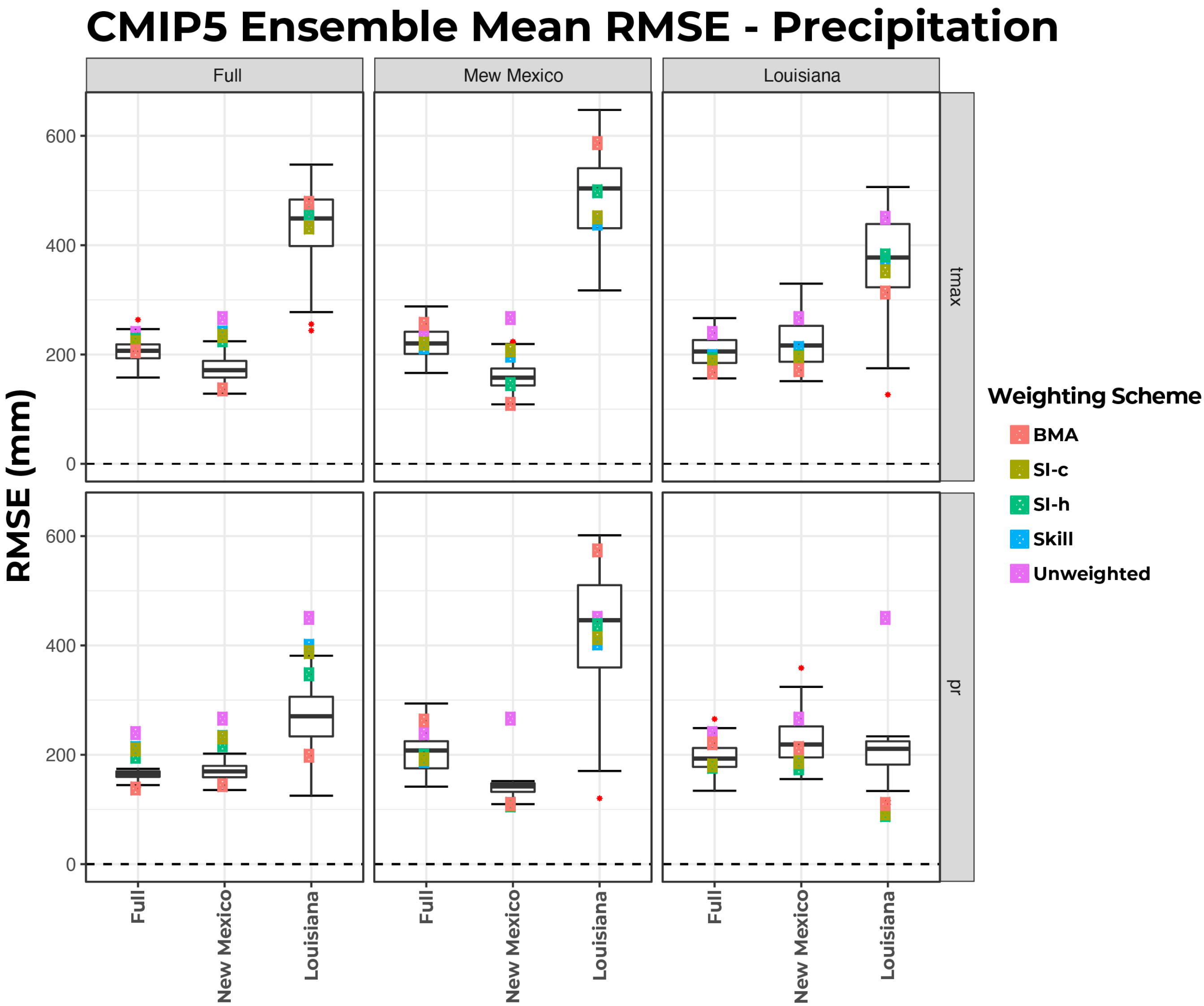

Figure S.3: Historical RMSE using all 48 weighting schemes, applied to precipitation (pr) to all three domains for the CMIP5 ensemble. The top row is the results from weighting schemes derived with tmax, and the bottom row is the results from weighting schemes derived with pr. The left column is the results for weighting derived using the full domain, the middle column is the results for weighting derived using the New Mexico domain, and the right column is the results for weighting derived using the Louisiana. Within a given domain and variable, the results are shown from left to right for the domain the weights are applied to. The boxplots are the results from the 100 BMA posterior weights, with red dots used to represent outliers.

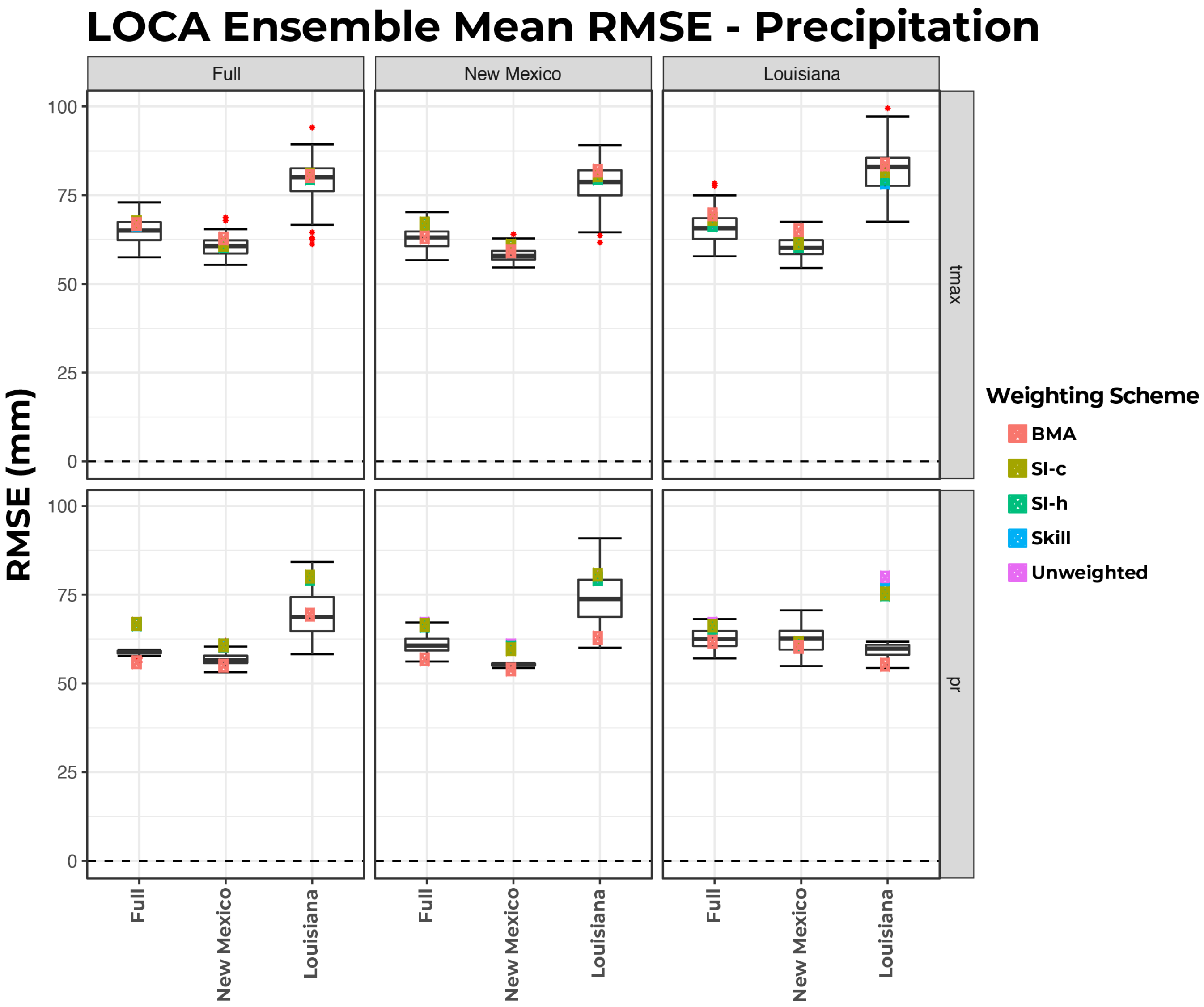

Figure S.4: Same as Figure S3 for the LOCA ensemble precipitation.

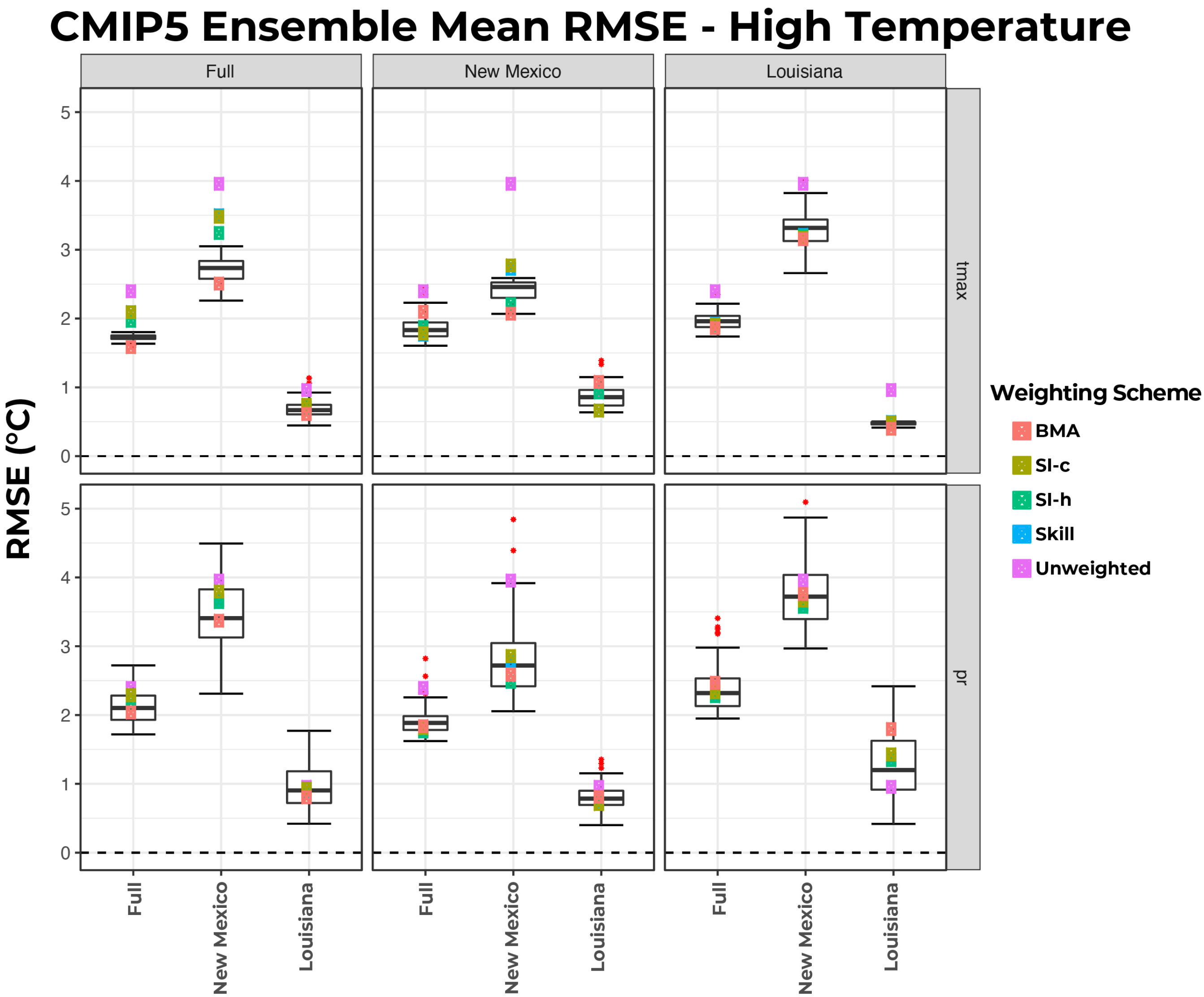

Figure S.5: Historical RMSE using all 48 weighting schemes, applied to high temperature (tmax) to all three domains for the CMIP5 ensemble. The top row is the results from weighting schemes derived with tmax, and the bottom row is the results from weighting schemes derived with pr. The left column is the results for weighting derived using the full domain, the middle column is the results for weighting derived using the New Mexico domain, and the right column is the results for weighting derived using the Louisiana. Within a given domain and variable, the results are shown from left to right for the domain the weights are applied to. The boxplots are the results from the 100 BMA posterior weights, with red dots used to represent outliers.

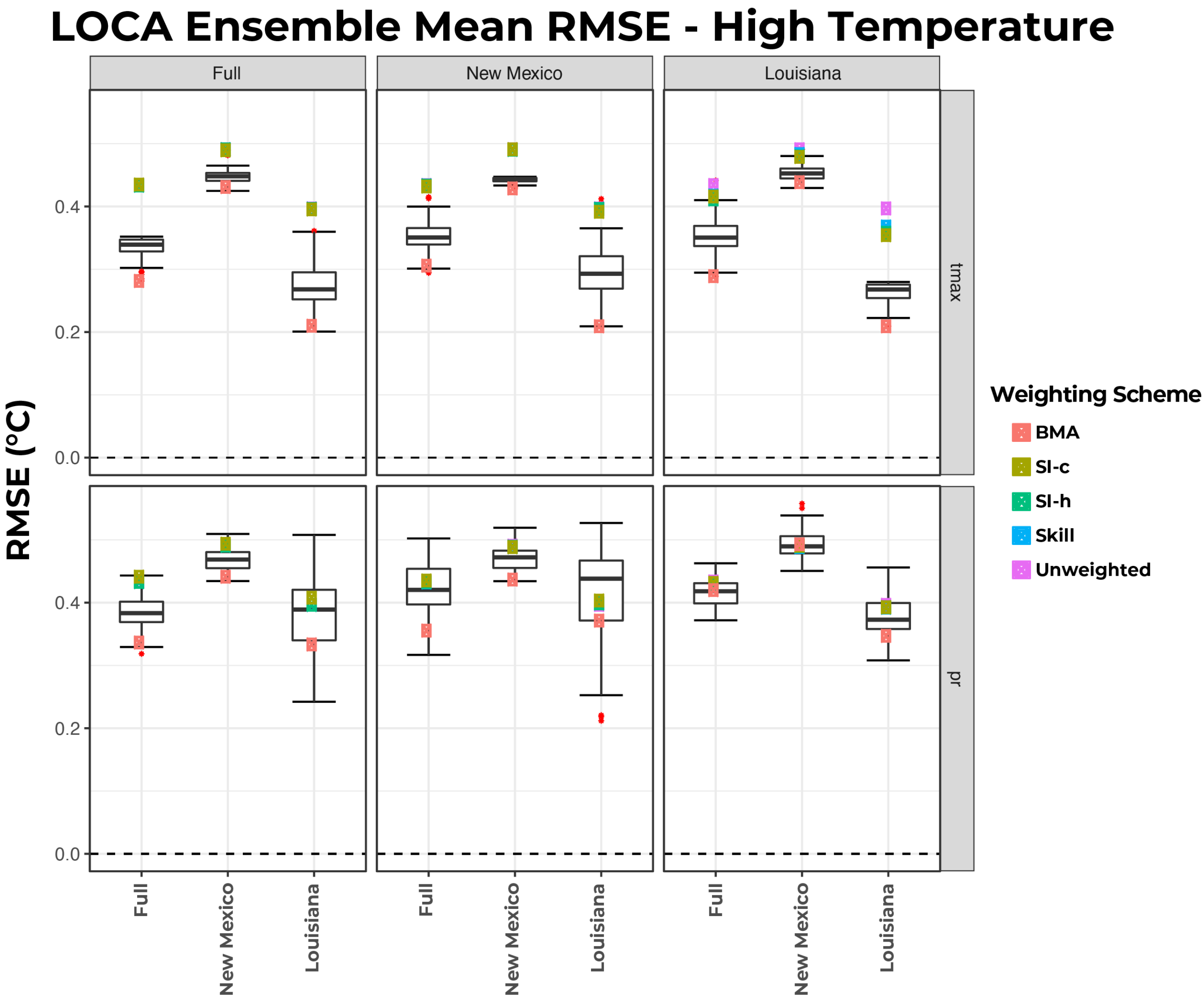

Figure S.6: Same as Figure S5 for the LOCA ensemble high temperature.

Table S1. Global Climate Models used to create both the CMIP5 and LOCA ensembles (adopted from Wootten et al. 2020a).

Modeling Center or Group	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1-0
		ACCESS1-3
Beijing Climate Center, China Meteorological Administration	BCC	bcc-csm1-1-m
Canadian Centre for Climate Modelling and Analysis	CCCMA	CanESM2
National Center for Atmospheric Research	NCAR	CCSM4
Community Earth System Model Contributors	NSF-DOE-NCAR	CESM1-BGC
		CESM1-CAM5
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC	CMCC-CM
		CMCC-CMS
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-QCCCE	CSIRO-Mk3-6-0
EC-EARTH consortium	EC-EARTH	EC-EARTH
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	LASG-CESS	FGOALS-g2
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM3
		GFDL-ESM2G
		GFDL-ESM2M
NASA Goddard Institute for Space Studies	NASS GISS	GISS-E2-H
		GISS-E2-R
Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR
		IPSL-CM5A-MR
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	MIROC5

Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC	MIROC-ESM-CHEM
		MIROC-ESM
Max Planck Institute for Meteorology	MPI-M	MPI-ESM-LR
		MPI-ESM-MR
Meteorological Research Institute	MRI	MRI-CGCM3
Norwegian Climate Centre	NCC	NorESM1-M